IBOC AM Transmission Specification

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iBiquity Digital Corporation

8865 Stanford Boulevard, Suite 202
Columbia, Maryland 21045
(410) 872-1530

20 Independence Boulevard
Warren, New Jersey 07059
(908) 580-7000

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SCOPE

The iBiquity Digital Corporation's digital audio broadcasting system is designed to permit a smooth evolution from current analog Amplitude Modulation (AM) and Frequency Modulation (FM) radio to a fully digital in-band on-channel (IBOC) system. This system delivers digital audio and data services to mobile, portable, and fixed receivers from terrestrial transmitters in the existing Medium Frequency (MF) and Very High Frequency (VHF) radio bands. Broadcasters may continue to transmit analog AM and FM simultaneously with the new, higher-quality and more robust digital signals, allowing themselves and their listeners to convert from analog to digital radio while maintaining their current frequency allocations

ABBREVIATIONS, SYMBOLS, AND CONVENTIONS

Introduction

Section **0** presents the following items pertinent to a better understanding of this document:

- Abbreviations and Acronyms
- Presentation Conventions
- Mathematical Symbols
- AM System Parameters

Noie:* *A glossary defining the technical terms used herein is provided at the end of this document

Abbreviations and Acronyms

AAB	Analog Audio Bandwidth Control
AABI	Analog Audio Bandwidth Indicator
AM	Amplitude Modulation
BC	L1 Block Count
BPSK	Binary Phase Shift Keying
CC	Control Channel
DD	Analog Diversity Delay Control
DDI	Analog Diversity Delay Indicator
DL	Data Link
EAS	Emergency Alert System
FCC	Federal Communications Commission
FM	Frequency Modulation
FT	File Transfer
GCS	Grounded Conductive Structures
GPS	Global Positioning System
HTML	Hypertext Markup Language
IBOC	In-band On-channel
IDS	IBOC Data Service
IP	Interleaving Process
ISI	Intersymbol Interference
JPG	Joint Photographic Experts Group
L1	Layer 1
L2	Layer 2
MA1-MA4	AM Service Modes 1 through 4
MF	Medium Frequency
MPA	Main Program Audio
MPD	Main Program Data
MUX	Multiplexer
N/A	Not Applicable
OFDM	Orthogonal Frequency Division Multiplexing
OSI	Open Systems Interconnection
P1-P3	Primary Logical Channels 1 through 3
PAC	Perceptual Audio Code

PDF	Portable Document Format
PIDS	Primary IBOC Data Service Logical Channel
PL	Power Level Control
PLI	Power Level Indicator
PSM	Service Mode Control
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RSID	Reference Subcarrier Identification
SAP	Service Access Point
SCCH	System Control Channel
SDU	Service Data Unit
SMI	Service Mode Indicator
TBD	To Be Determined
UTC	Universal Time Coordinated
VHF	Very High Frequency
WML	Wireless Markup Language
XML	extensible Markup Language

Presentation Conventions

Unless otherwise noted, the following conventions apply to this document:

Information enclosed in braces { } is either unavailable at the present time or subject to change.
Glossary terms are presented in italics upon their first usage in the text.
All vectors are indexed starting with 0.
The element of a vector with the lowest index is considered to be first.
In drawings and tables, the leftmost bit is considered to occur first in time in time.
Bit 0 of a byte or word is considered the least significant bit.
When presenting the dimensions of a matrix, the number of rows is given first (e.g., an n x m matrix has n rows and m columns).
In timing diagrams, earliest time is on the left.
Binary numbers are presented with the most significant bit having the highest index.
In representations of binary numbers, the least significant bit is on the right.

Mathematical Symbols

Variable Naming Conventions

The variable naming conventions defined helow are used throughout this document.

Category	Pefinition	Examples
Lower and upper case letters	Indicates scalar quantities	i, j, J, g_{11}
Underlined lower and upper case letters	Indicates vectors	$\underline{u}$ $\underline{V}$
Double underlined lower and upper case letters	Indicates two-dimensional matrices	$\underline{\underline{u}}$, $\underline{\underline{V}}$
[i]	Indicates the i^{th} element of a vector, where i is a non-negative integer	$\underline{u}$[0], $\underline{V}$[1]
[ ]	Indicates the component of a vector	$\underline{v}$ = [0, 10, 6, 4]

Category	Definition	Examples
[i] [j]	Indicates the element of a two-dimensional matrix in the i^{th} row and j^{th} column, where i and j are non-negative integers	u[i][j], V[i][j]
$\begin{bmatrix} & \\ & \end{bmatrix}$	Indicates the components of a matrix	$\underline{\underline{m}} = \begin{bmatrix} 0 & 3 & 1 \\ 2 & 7 & 5 \end{bmatrix}$
n ...m	Indicates all the integers from n to m, inclusive	3 ...6 = 3, 4, 5, 6
n:m	Indicates bit positions n through m of a binary sequence or vector	Given a binary vector i = [0, 1, 1, 0, 1, 1, 0, 0], $i_{2:5}$ = [1, 0, 1, 1]

Arithmetic Operators

The arithmetic operators defined beiow are used throughout this document.

Category	Definition	Examples
	Indicates a multiplication operation	3.4 = 12
INT( )	Indicates the integer portion of a real number	INT(5/3) = 1 INT(-1.8) = -1
a MOD b	Indicates a modulo operation	33 MOD 16 = 1
⊕	Indicates modulo-2 binary addition	1 ⊕ 1 = 0
|	Indicates the concatenation of two vectors	B = [S | F] The resulting vector B consists of the elements of S followed by the elements of F.
J	Indicates the square-root of -1	$i = \sqrt{-1}$
Re( )	Indicates the real component of a complex quantity	If x = (3 + j4), Re(x) = 3
Im( )	Indicates the imaginary component of a complex quantity	If x = (3 + j4), Im(x) = 4
$\log_{10}$	Indicates the base-IO logarithm	$\log_{10}(100) = 2$
*	Indicates complex conjugate	If x = (3 + j4), x* = (3 - j4)

AM System Parameters

The AM system parameters defined helow are used throughout this document.

Parameter Name	Symbol	Units	Exact Value	Computed Value (to 4 significant figures)
OFDM Subcarrier Spacing	Δf	Hz	1488375/8192	181.7
Cyclic Prefix Width	α	none	7/128	5.469×10^{-2}
OFDM Symbol Duration	T_s	Sec.	$(1+\alpha) / \Delta f = (135/128) \cdot (8192/1488375)$	5.805×10^{-3}
OFDM Symbol Rate	R_s	Hz	$= 1/T_s$	172.3
L1 Frame Duration	T_f	Sec.	$65536/44100 = 256 \cdot T_s$	1.486
L1 Frame Rate	R_f	Hz	$= 1/T_f$	6.729×10^{-1}
L1 Block Duration	T_b	Sec.	$= 32 \cdot T_s$	1.858×10^{-1}
L1 Block Rate	R_b	Hz	$= 1/T_b$	5.383
Digital Diversity Delay Frames	N_{dd}	none	3	3
Diversity Delay Time	T_{dd}	Sec.	$= N_{dd} \cdot T_f$	4.458

IBOC LAYERS

The IBOC detailed performance specifications are organized in terms of the International Standards Organization Open Systems Interconnection (ISO OSI) layered model. The definitions of this model are summarized below for reference

- Layer 5 (Application) – presents content to the user (program source or listener).
- Layer 4 (Encoding)– content-specific source coding (e.g., PAC, HTML) as well as station identification and control capabilities.
- Layer 3 (Transport) – one or more application-specific protocols tailored to provide robust and efficient transfer of Layer 4 data. Also provides generic packet and/or file-based services.
- Layer 2 (Service Mux)–limited error detection, addressing, Layer 3 multiplexing to logical channels.
- Layer 1 (Physical Layer) – modulation, framing, and signal processing (encoding, interleaving, etc.) to the specified grade of service.

Each OSI layer of the broadcasting system has a corresponding layer, termed a peer, in the receiving system. The functionality of these layers is such that the combined result of lower layers is to effect a virtual communication between a given layer and its peer on the other side.

For the purposes of this document covering the IBOC Transmission System only Layer 1 will be described.

Introduction

Layer 1 of the AM system converts information and ***system*** control from ***layer*** 2 (L2) into an AM IBOC waveform for transmission in the existing allocation in the MF band. The information and control is transported in discrete ***transfer frames*** via multiple ***logical channels*** through the layer 1 ***service access point*** (SAP). Information transfer frames are referred to as layer 1 ***service data units*** (SDUs).

The L1 SDUs vary in size and format depending on the ***service mode.*** The service mode, a major component of system control, determines the transmission characteristics of each logical channel. After assessing the requirements of their candidate applications, higher protocol layers select service modes that most suitably configure the logical channels. The plurality of logical channels reflects the inherent flexibility of the system, which supports simultaneous delivery of various classes of digital audio and data.

This section presents the following:

- An overview of the waveforms and spectra
- An overview of the system control, including the available service modes
- An overview of the logical channels
- A high-level discussion of each of the functional components comprising the layer 1 AM air interface

Note: Throughout this document, various system parameters are globally represented as mathematical symbols. Refer to Subsection 2.5 for their values.

Waveforms and Spectra

The design provides a flexible means of transitioning to a digital broadcast system by providing two new waveform types: Hybrid and All Digital. The Hybrid waveform retains the analog AM signal, while the All Digital waveform does not. Both new waveform types conform to the currently allocated ***spectral emissions mask.***

The ***digital signal*** is modulated using ***orthogonal frequency division*** multiplexing (OFDM). OFDM is a parallel modulation scheme in which the data stream modulates a large number of orthogonal subcarriers that are transmitted simultaneously. OFDM is inherently flexible, readily allowing the mapping of logical channels to different groups of subcarriers.

Refer to Section 0 for a detailed description of the spectra of the two waveform types

Hybrid **Waveform**

In the Hybrid waveform, the digital signal is transmitted in ***primary*** and secondary ***sidebands*** on either side of the host analog signal, as well as underneath the host analog signal in ***tertiary sidebands.***

The total power of all the digital sidebands is significantly below the total power in the analog AM signal. The level of each OFDM subcarrier within a given primary or secondary sideband is fixed at a constant value. Primary or secondary sidebands may be scaled relative to each other.

In the tertiary sideband, the OFDM subcarrier power levels for the hybrid waveform are not fixed, but may be adjusted. In addition, there are two reference subcarriers for system control whose levels are fixed at a value that is different from the other sidebands.

The analog host is a monophonic signal. The Hybrid system does not support analog AM stereo transmissions

All Digital Waveform

The greatest system enhancements are realized with the All Digital waveform. In this waveform the analog signal is replaced with the primary sidebands whose power is increased relative to the Hybrid waveform levels. In addition, the secondary and tertiary sidebands are moved to either side of the primary sidebands and their power is also increased relative to the Hybrid levels. The end result is a higher power digital signal with an overall bandwidth reduction. These changes provide a more robust digital signal that is less susceptible to adjacent channel interference. Reference subcarriers are also provided to convey system control information. Their levels are fixed at a value that is different from the other sidebands.

System Control Channel

The ***system control channel*** (SCCH) transports control and status information. The ***service mode*** control (PSM), ***analog diversity delay control*** (DD), ***analog audio bandwidth control*** (AAB), and ***power level control (PL)*** are all sent from layer 2 to layer 1, while synchronization information is sent from layer 1 to layer 2. In addition, several bits of the system control data sequence designated "reserved" are controlled from layers above L1 via the "reserved control data" interface.

Four service modes dictate all permissible configurations of the logical channels. They are:

1. Hybrid service mode MA1
2. Hybrid service mode MA2
3. All Digital service mode MA3
4. All Digital service mode MA4

Logical Channels

A logical channel is a signal path that conducts L1 **SDUs** in transfer frames into and out of layer **1** with a specific grade of service, determined by service mode. Layer 1 of the AM air interface provides four logical channels to higher layer protocols: **P1, P2, P3** and **PIDS. P1, P2** and **P3** are intended for general purpose audio and data transfer, while the **PIDS** channel is designed to cany the IBOC data services (IDS) information. The **P1** and **P2** logical channels are designed to be more robust than the **P3** logical channel. Logical channels **P1** and **P3** are available **for** all services modes, while **P2** is only available for specific service modes. This allows a transfer of information that can be tailored to conform to a number of diverse applications.

Modes MA2 and MA4 provide higher throughput than MA1 and MA3 by making available an additional logical channel (i.e. **P2)** at the expense of **P1** robustness. The approximate information rates of the four logical channels for each of the four service modes are shown in Table 0-1.

Table 0-1 Approximate Information Rate of **AM** Logical Channels

Service Mode	Approximate Channel Information Rate (kbps)				Waveform
	P1	P2	P3	PIDS	
MA1	20	0	16	0.4	Hybrid
MA2	20	20	16	0.4	Hybrid
MA3	20	0	20	0.4	All Digital
MA4	20	20	20	0.4	All Digital

The performance of each logical channel is completely described through three ***characterization parameters: transfer, latency,*** and ***robustness. Channel encoding, spectral*** mapping ***interleaver depth,*** and ***diversity delay*** are the components of these characterization parameters. The service mode uniquely configures these components for each active logical channel, thereby allowing the assignment of appropriate characterization parameters.

In addition, the service mode specifies the framing and synchronization of the transfer frames through each active logical channel.

Functional Components

This subsection includes a high-level description of each layer 1 functional block and the associated signal flow. Figure 0-1 is a functional block diagram of the layer 1 processing. Audio and data are passed from the higher OSI layers to the physical layer, the modem, through the Layer 1 Service Access points.

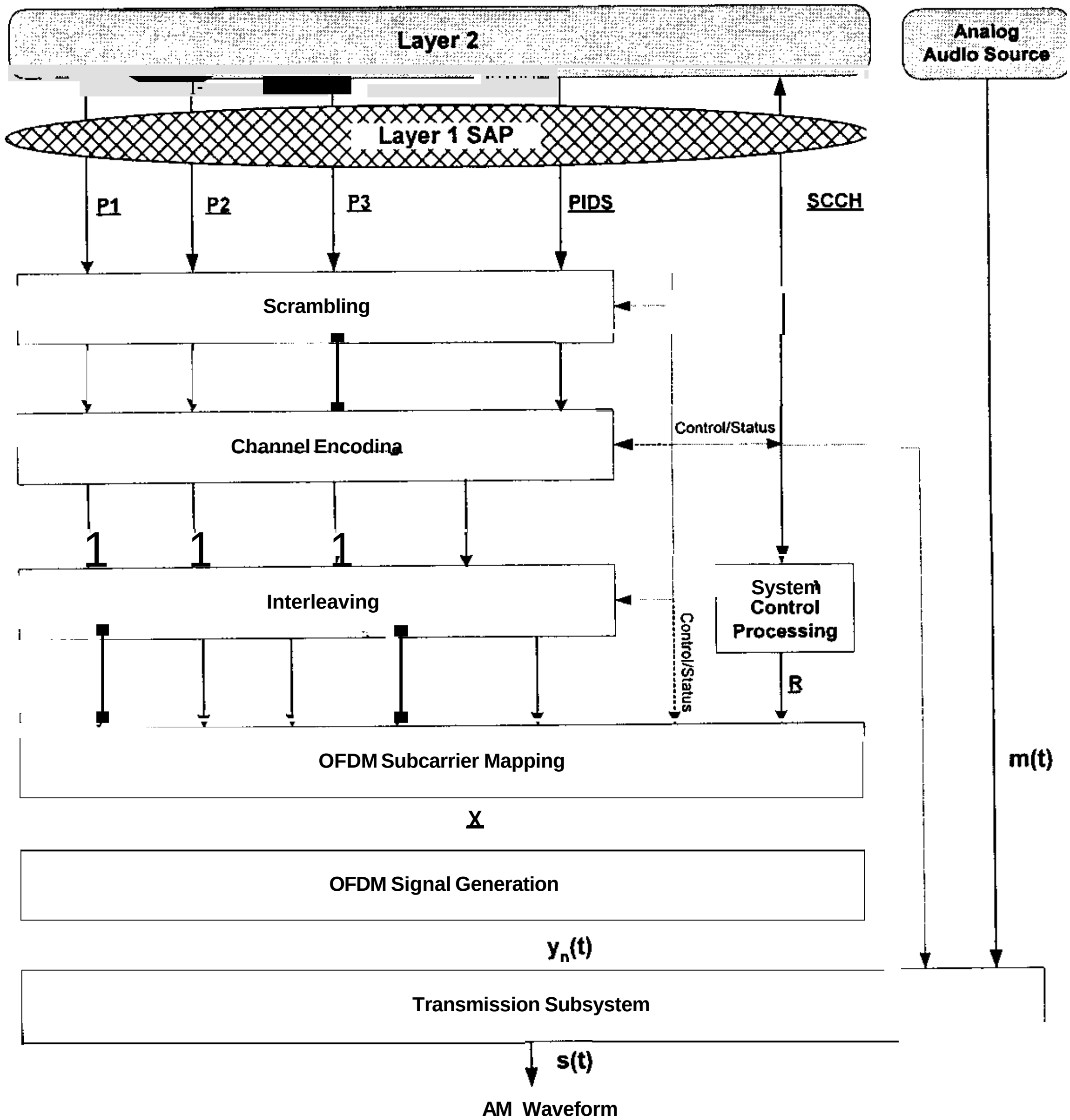

Figure 0-1 AM Air Interface L1 Functional Block Diagram

L1 Service Access Point

The L1 SAP defines the interface between layer 2 and layer 1 of the system protocol stack. Each channel enters layer 1 in discrete transfer frames, with a unique size and rate determined by service mode. Transfer frames which cany information from layer 2 are referred to as L1 SDUs.

Scrambling

This function randomizes the digital data carried in each logical channel to mitigate signal periodicities. At the output of scrambling, the logical channel vectors retain their identity.

Channel Encoding

This function **uses** ***convolutional encoding*** to add redundancy to the digital data in each logical channel to improve its reliability in the presence of channel impairments. The size of the logical channel vectors is increased in inverse proportion to the code rate. The encoding techniques are configurable by service mode. Diversity delay is also imposed on selected logical channels. At the output of the channel encoder, the logical channel vectors retain their identity.

Interleaving

Interleaving in time and frequency is employed to mitigate the effects of burst errors. The interleaving techniques are tailored to the MF non-uniform interference environment and are configurable by service mode. In this process, the logical channels lose their identity

System Control Processing

This function generates a vector of ***system control data sequences*** that includes system control information received from layer 2 (such as service mode), and status for broadcast on the reference subcarriers.

OFDM Subcarrier Mapping

This function assigns the interleaver matrices and system control vector to ***OFDM subcarriers***. One row of each active interleaver matrix and one hit of the system control vector is processed each OFDM ***symbol*** (every T_S seconds) to produce one output vector $\underline{X}$, which is a frequency domain representation of the signal. The mapping is specifically tailored to the non-uniform interference environment encountered in the AM band and is a function of the service mode.

OFDM Signal Generation

This function generates the digital portion of the time-domain AM IBOC waveform. The input vectors $\underline{\mathbf{X}}$ are transformed into a shaped time-domain baseband pulse, $\mathbf{y_n(t)}$, defining one OFDM symbol.

Transmission Subsystem

This function formats the baseband waveform for transmission through the MF channel. Major sub-functions include pre-compensation, symbol concatenation, and frequency up-conversion. When transmitting the Hybrid waveform, this function modulates the AM analog audio source and combines it with the digital signal to form a composite Hybrid signal, s(t), ready for transmission.

FUNCTIONAL DESCRIPTION

Introduction

OFDM signal generation receives complex frequency-domain OFDM symbols from the output of OFDM subcarrier mapping and outputs time-domain pulses representing the digital portion of the AM IBOC signal. A conceptual block diagram of OFDM signal generation is shown in Figure 0-1 OFDM Signal Generation Conceptual Block Diagram.

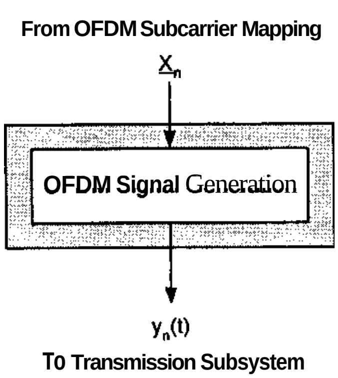

Figure 0-1 OFDM Signal Generation Conceptual Block Diagram

The input to OFDM signal generation is a complex vector, $\underline{X}_n$ **of** length **L,** representing the complex constellation values **for** each OFDM subcarrier in OFDM symbol n. The output **of** OFDM signal generation is a complex, baseband, time-domain pulse $y_n(t)$, representing the digital portion **of** the AM **IBOC** signal **for** symbol n.

Functionality

Let $\underline{X}_n[k]$ he the complex scaled constellation points from OFDM subcarrier mapping **for** the n^{th} symbol, where k = 0, I, ..., L-1 indexes the OFDM subcarriers. Let $y_n(t)$ denote the complex time-domain output of OFDM signal generation for the n^{th} symbol. Then $y_n(t)$ can be written in terms of $\underline{X}_n[k]$ as follows:

$$y_n(t) = W(t - nT_s) \cdot \sum_{k=0}^{L-1} \underline{X}_n[k] \cdot e^{j2\pi\Delta f\left[k-\left(\frac{L-1}{2}\right)\right]\cdot(t-nT_S)}$$

where n = 0,1,...,∞, $0 \le t \le \infty$, L = **163** is the minimum number **of** OFDM subcarriers, and T_S and **Δf** ***are*** the OFDM symbol period and OFDM subcarrier spacing, respectively, **as** defined in Section 0.

The pulse-shaping ***function*** $W(\xi)$ is defined as:

$$W(\xi) = \begin{cases} 0 & for\ \xi < 0 \\ \sqrt{\frac{1}{3\sqrt{2\pi}} \int_{-\infty}^{\infty} e^{-4050\left(\frac{\tau}{T_s}\right)^2} H(\xi-\tau)d\tau} & for\ 0 \le \xi \le \frac{348}{270}T_S \\ 0 & for\ \ \xi > \frac{348}{270}T_S \end{cases}$$

where

$$H(\xi) = \begin{cases} 0.5 \cdot \left[1 + cos\left(\pi \frac{\alpha T - \xi}{\alpha T}\right)\right], & for\ 0 < \xi \le \alpha T \\ 1.0, & for\ \alpha T < \xi < T \\ 0.5 \cdot \left[1 + cos\left(\pi \frac{\xi - T}{\alpha T}\right)\right], & for\ T \le \xi \le (1+\alpha)T \\ 0, & otherwise \end{cases}$$

α is the cyclic prefix width defined in Subsection 0, and T = **1/Δf** is the reciprocal **of** the OFDM subcarrier spacing. Figure 0-2 Pulse Shaping Function shows a plot of the pulse shaping function $W(\xi)$.

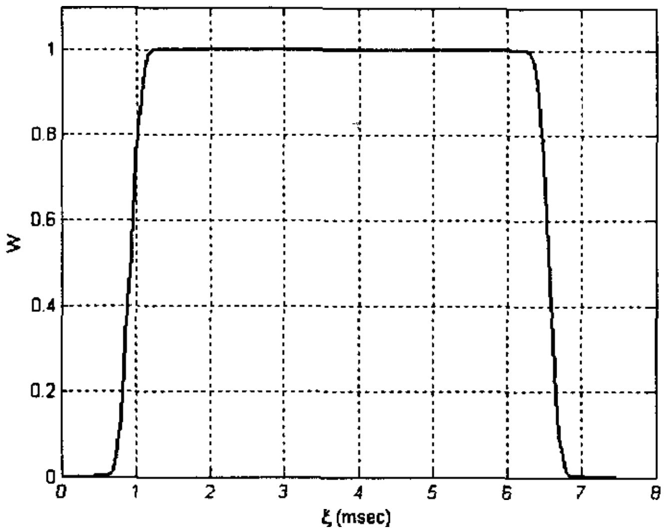

Figure 0-2 Pulse Shaping Function

Transmission Subsystem

Introduction

The transmission subsystem formats the baseband AM IBOC waveform for transmission through the MF channel. Functions include symbol concatenation, pre-compensation and frequency up-conversion. In addition, when transmitting the Hybrid waveform, this function delays, filters, and modulates the baseband analog audio signal before coherently combining it with the digital portion of the waveform.

The input to this module is a complex, baseband, time-domain OFDM symbol, $y_n(t)$, from OFDM signal generation. A baseband analog audio signal, $m(t)$, is also input from an analog source when transmitting the Hybrid waveform. In addition, analog diversity delay control (DD) is input from layer 2 via the SCCH. The output of this module is the MF AM IBOC waveform.

Refer to Figure 0-3 Hybrid Transmission Subsystem Functional Block Diagram and Figure 0-4 All Digital Transmission Subsystem Functional Block Diagram for functional block diagrams of the Hybrid and All Digital transmission subsystems, respectively.

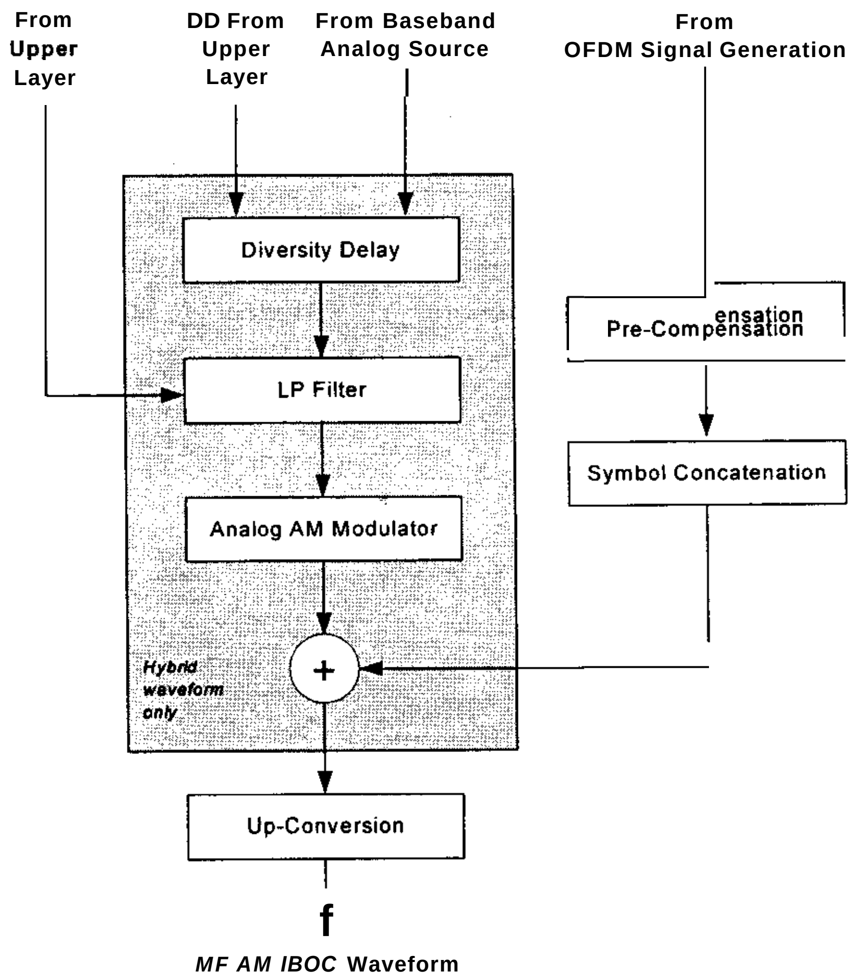

Figure 0-3 Hybrid Transmission Subsystem Functional Block Diagram

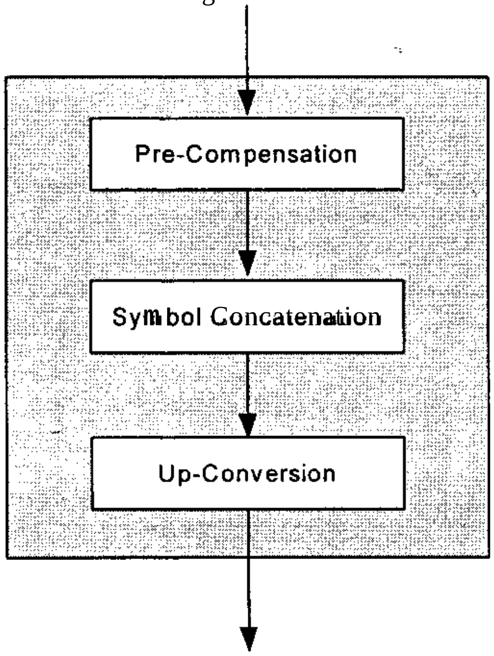

Figure 0-4 All Digital Transmission Subsystem Functional Block Diagram

Functional Components

The functional components of the transmission subsystem are specified in Subsections 0 through 0.

Symbol Concatenation

The individual time-domain OFDM symbols output from ISI pre-compensation are summed to produce a continuum of pulses over $0 \le t \le \infty$ as follows:

$$y(t) = \sum_{n=0}^{\infty} y'_n(t)$$

Diversity Delay

When broadcasting the Hybrid waveform, y(t) is combined with the analog host AM signal a(t), as shown in Figure 0-3 Hybrid Transmission Subsystem Functional Block Diagram. The first step in generating a(t) is the application of diversity delay to the baseband analog audio signal m(t).

The analog diversity delay control bit (DD), received from layer 2 via the SCCH, to enable or disable the diversity delay. If DD is 0, the diversity delay is disabled; if DD is 1, it is enabled. When diversity delay is enabled, an adjustable delay τ_d is applied to the baseband analog audio signal m(t). The delay is set so that, at the output of the analog/digital combiner, a(t) lags the audio content of the corresponding digital signal, y(t), by T_{dd}. For example, if both the analog and digital signals carry the same audio program, the analog audio would be delayed from the corresponding digital audio by T_{dd} at the output of the analog/digital combiner. The delay is adjustable to account for processing delays in the analog and digital chains. When the state of DD changes while operating in service mode MA1 or MA2, there will be a discontinuity in the analog signal.

The absolute accuracy of the diversity delay, when enabled, is defined in Supplement A

Low Pass Filtering

In hybrid mode, this process low pass filters the analog audio data according to the state of the **AAB** control received from layer 2. If the control bit is zero, the analog audio is filtered to a 5 kHz bandwidth according to the specifications in Supplement **A.** If the control bit is one, the analog audio is filtered to an **8** kHz bandwidth according to the specifications in Supplement **A.**

Analog AM Modulator

When broadcasting the hybrid waveform, this process computes the envelope of the analog **AM** signal by applying a modulation index and adding a DC offset and **as** follows:

$$a(t) = [1 + g \cdot m(t - T_{dd})]$$

where $a(t)$ is the envelope, $m(t-T_{dd})$ is the delayed analog source and g is the modulation gain. Typically, $g = 1.25$, representing a +125% modulation level. The input analog audio source, $m(t)$, must be preprocessed external to the **AM** IBOC exciter, so that $a(t)$ does not assume negative values. See Supplement **A** for a complete description of the requirements on the input analog audio source.

Analog/Digital Combiner

When broadcasting the Hybrid waveform, the real analog **AM** baseband waveform, $a(t)$, is coherently combined with the digital baseband waveform, $y(t)$, to produce the complex baseband **AM IBOC** Hybrid waveform $z(t)$, as follows:

$$\mathrm{Re}\,[z(t)] = \mathrm{Re}\,[y(t)] + a(t)$$

$$\mathrm{Im}\,[z(t)] = \mathrm{Im}\,[y(t)]$$

The levels of the digital sidebands in the output spectrum are appropriately scaled by **OFDM** subcarrier mapping **as** shown in Supplement **A,** Section 6.4.

Changing service modes form **MA1** to **MA2** or **MA2** to **MA1** shall not cause any interruptions or discontinuities in the analog signal. Refer to Supplement **A** for further details.

Up-Conversion

The concatenated digital signal $z(t)$ is translated from baseband to the RF carrier frequency as follows:

$$s(t) = \mathrm{Re}\left(e^{j2\pi f_c t} \cdot z(t)\right)$$

where f_c is the RF channel frequency and Re( ) denotes the real component of the complex quantity. For the **All** Digital waveform, $z(t)$ is replaced with $y(t)$.

The **AM** IBOC **DAB** waveform is broadcast in the current **AM** radio band and its power levels and spectral content are limited to be within the spectral mask as defined in 47 **CFR** 573.44. See Supplement **A.**

The carrier frequency spacing and channel numbering schemes are compatible with 47 CFR §73.14. Channels are centered at **10** kHz intervals ranging from 540 to 1700 kHz. Both the analog and digital portion of the hybrid waveform are centered **on** the same carrier frequency. The absolute accuracy of the carrier frequency is defined in Supplement A.

GPS Synchronization

In order to ensure precise time synchronization and rapid station acquisition each station is GPS synchronized. This is normally accomplished through synchronization with a signal synchronized in time and frequency to the Global

Positioning System (GPS)[86]. Transmissions that are not locked to GPS, will not benefit from fast tuning since they cannot be synchronized with other stations".

WAVEFORMS AND SPECTRA

Introduction

This section describes the output spectrum for Hybrid and All Digital waveforms. Each spectrum is divided into several sidebands, which represent various subcarrier groupings. All spectra are represented at baseband.

Spectral Conventions

Each spectrum described in the following subsections shows the subcarrier number and center frequency of certain key OFDM subcarriers. The center frequency of a subcarrier is calculated by multiplying the subcarrier number by the OFDM subcarrier spacing Af. The center of subcarrier ***0*** is located at ***0* Hz.** In this context, center frequency is relative to the radio frequency (RF) ***allocated channel.***

For example, subcarriers **57** and **81,** whose center frequencies are located at **10356.12488** Hz and **14716.59851** Hz, respectively, bound the primary upper sideband of the Hybrid waveform. Refer to Table ***0***-1. Thus, the frequency span of the primary upper sideband is **4360.47363 Hz (14716.59851 – 10356.12488).**

Hybrid Spectrum

The digital signal is transmitted in primary and secondary sidebands on either side of the analog host signal, as well as in tertiary sidebands beneath the analog host signal **as** shown in Figure 0-1. In addition, status and control information is transmitted on reference subcarriers located on either side of the main carrier. Each sideband has both an upper and a lower component. The PIDS logical channel is transmitted in individual subcarriers just above and below the frequency edges of the upper and lower secondary sidebands. The power level of each OFDM subcarrier is fixed relative to the unmodulated main analog carrier. However, the power level of the secondary, PIDS, and tertiary subcarriers is adjustable.

Table 0-1 summarizes the spectral characteristics of the Hybrid waveform. Individual subcarriers are numbered from **-81** to **81** with the center subcarrier at subcarrier number 0. Table 0-1 lists the approximate frequency ranges and bandwidths for each sideband. In Table **0-1,** the subcarriers **54** to **56** and **-54** to **-56** are not represented. This is because they are not transmitted to avoid interference with first adjacent signals.

The amplitude scale factors listed in Table 0-1 and Table 0-2 refer to the multiplication constants used to scale the individual subcarriers to the proper levels relative to the unmodulated main carrier. These scale factors are defined in Supplement **A.** Refer to Section 0 Digital Sideband Levels for details of the subcarrier scaling operation.

[86] GPS Locked stations are referred to as Level I: GPS-locked transmission facilities

[87] Level II: Non-GPS locked transmission facilities

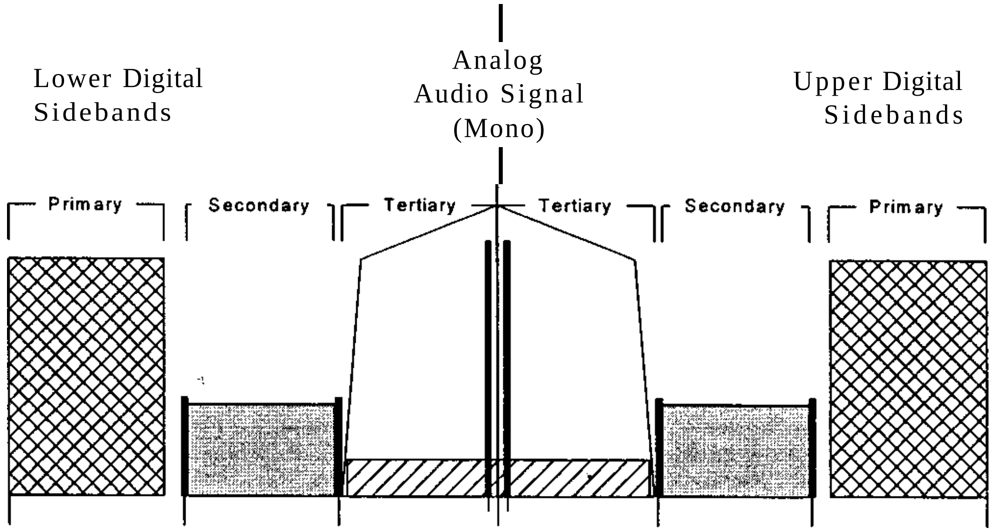

Table 0-1 AM Hybrid Waveform Spectral Summary

Sideband	Subcarrier Range	Subcarrier Frequencies (Hz from channel center)	Frequency Span (Hz)	Amplitude Scale Factor
Primary Upper	57 to 81	10356.1 to 14716.6	4360.5	CH_P
Primary Lower	-57 to -81	-10356.1 to -14716.6	4360.5	CH_P
Secondary Upper	28 to 52	5087.2 to 9447.7	4360.5	CH_{S1} or CH_{s2}
Secondary Lower	-28 to -52	-5087.2 to -9447.7	4360.5	CH_{S1} or CH_{s2}
Tertiary Upper	2 to 26	363.4 to 4723.8	4360.4	$\underline{CH_{T1}}$[0:24] $\underline{CH_{T2}}$[0:24]
Tertiary Lower	-2 to -26	-363.4 to -4723.8	4360.4	$\underline{CH_{T1}}$[0:24] $\underline{CH_{T2}}$[0:24]
Reference Upper	1	181.7	181.7	CH_B
Reference Lower	-1	-181.7	181.7	CH_B
IDS1	27	4905.5	181.7	CH_{I1} or CH_{I2}
IDS2	53	9629.4	181.7	CH_{I1} or CH_{I2}
IDS1*	-27	-4905.5	181.7	CH_{I1} or CH_{I2}
IDS2*	-53	-9629.4	181.7	CH_{I1} or CH_{I2}

All Digital Spectrum

In the All Digital waveform, the analog signal is replaced with higher power primary sidebands. The unmodulated AM carrier is retained. In addition, the secondary upper sideband moves to the higher frequencies above the primary upper sideband and the tertiary lower sideband moves to the lower frequencies below the primary lower sideband.

The secondary lower and tertiary upper sidebands are no longer used. Furthermore, the power of both the secondary and tertiary sidebands is increased. These changes result in the overall bandwidth being reduced, making the All Digital waveform less susceptible to adjacent channel interference. The reference subcarriers are located on either side of the unmodulated AM carrier as in the hybrid waveform, but at a higher level. The spectrum of the All Digital waveform is illustrated in Figure 0-2. The power level of each of the OFDM subcarriers within a sideband is fixed relative to the unmodulated main analog carrier. Table 0-2 summarizes the spectral characteristics of the All Digital waveform.

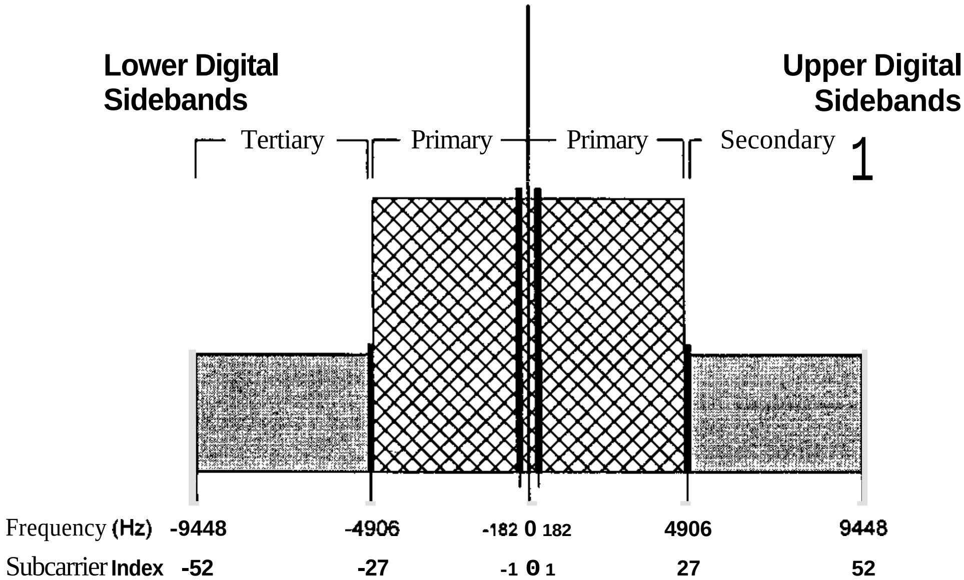

Figure 0-2 AM All Digital Waveform Spectrum

Table 0-2 AM All Digital Waveform Spectral Summary

Sideband	Subcarrier Range	Subcarrier Frequencies (Hz from channel center)	Frequency Span (Hz)	Scale Factor
Primary Upper	2 to 26	363.4 to 4723.8	4360.5	CD_P
Primary Lower	-2 to -26	-363.4 to –4723.8	4360.5	CD_P
Secondary	28 to 52	5087.2 to 9447.7	4360.5	CD_E
Tertiary	-28 to -52	-5087.2 to -9447.7	4360.5	CD_E
Reference Upper	1	181.7	181.7	CD_B
Reference Lower	-1	-181.7	181.7	CD_B
IDS1	27	4905.5	181.7	CD_I
IDS2	-27	4905.5	181.7	CD_I

SUPPLEMENT A AM TRANSMISSION SPECIFICATIONS

Introduction

This supplement presents the key transmission specifications for the AM IBOC system, as described in the body of this document.

Service Mode Switching

When the broadcaster changes the service mode, it is desirable to minimize any signal interruptions and make the transition as seamless as possible. However, different service modes may employ different diversity delays and interleaving so that truly seamless operation is not possible. The following requirements shall apply:

When the AM service mode is changed from any hybrid service mode (MA1, MA2) to any other hybrid service mode, the analog audio output shall not be interrupted.

When switching from any AM service mode to any other AM service mode, the reference broadcast system shall not interrupt digital audio and/or data services for more than 1 minute.

When switching from any AM service mode to any other AM service mode, the commercial broadcast system shall not interrupt digital audio and/or data services for more than 10 seconds.

Synchronization Tolerances

The system shall support **two** levels of synchronization for each broadcaster:

Level I: Network synchronized (Assumed using Global Positioning System (GPS) locked transmission facilities)

Level II: Non networked synchronized (Non-GPS-locked transmission facilities)
Normally, transmission facilities will operate as Level I facilities in order to support numerous advanced system features.

Analog Diversity Delay

The absolute accuracy of the analog diversity delay in the transmission signal will be within **f68** microseconds (μsec) for both synchronization Level **1** and Level II transmission facilities.

The absolute accuracy of the analog diversity delay in the receive system will be within **+68** microseconds (psec) for both synchronization Level I and Level II transmission facilities.

Diversity delay accuracy will be verified with a calibrated test receiver receiving the RF **channel** under test. A digitally generated 4-kHz sinusoidal test tone at a level of -6 dB from full scale will be applied to both the analog and digital transmit signal paths. The tone will be a pulsed signal, consisting of a repeating pattern of 0.5 seconds on, followed by **4.5** seconds off.

Time and Frequency Accuracy and Stability

The total modulation symbol-clock frequency absolute error shall be budgeted according to the following requirements:

For the entire end-to-end system:	±101 ppm maximum
Caused by the receive system:	±100 pprn maximum
Caused by the broadcast system:	±1 ppm maximum for synchronization Level I facilities
	±.01 pprn maximum for synchronization Level I1 facilities

The total carrier frequency absolute error shall be budgeted according to the following requirements:

The total (analog and digital) carrier frequency absolute error of a synchronization Level I broadcast system as observed at the RF output shall be ±.02 **Hz** maximum.

The total (analog and digital) carrier frequency absolute error of a synchronization Level II broadcast system as observed at the RF output shall be ±2.0 **Hz** maximum.

The total (analog and digital) carrier frequency absolute error **as** observed at the receiver baseband demodulator input shall be:

Due to the entire end-to-end system: ±1272 **Hz** maximum
(Refer to **[1]** Subsection **8.4)**

Due to the receive system only: +1270 Hz
(exclusive of the broadcast system errors specified in object **IDs** SY1012-39 and SY1012-40)

It is recommended that all carrier and clock oscillators be frequency-locked to the same reference within the

Offset From Carrier Frequency	Level Relative To Unmodulated Carrier
10.2 to 20 kHz	-25 dB
20 to 30 kHz	-35 dB
30-60 kHz	-5 - 1 dB/kHz
60-75 kHz	-65 dB
> 75 kHz	-80 or [-43 - $10 \cdot \log_{10}$ (power in watts)] dBc, whichever is less

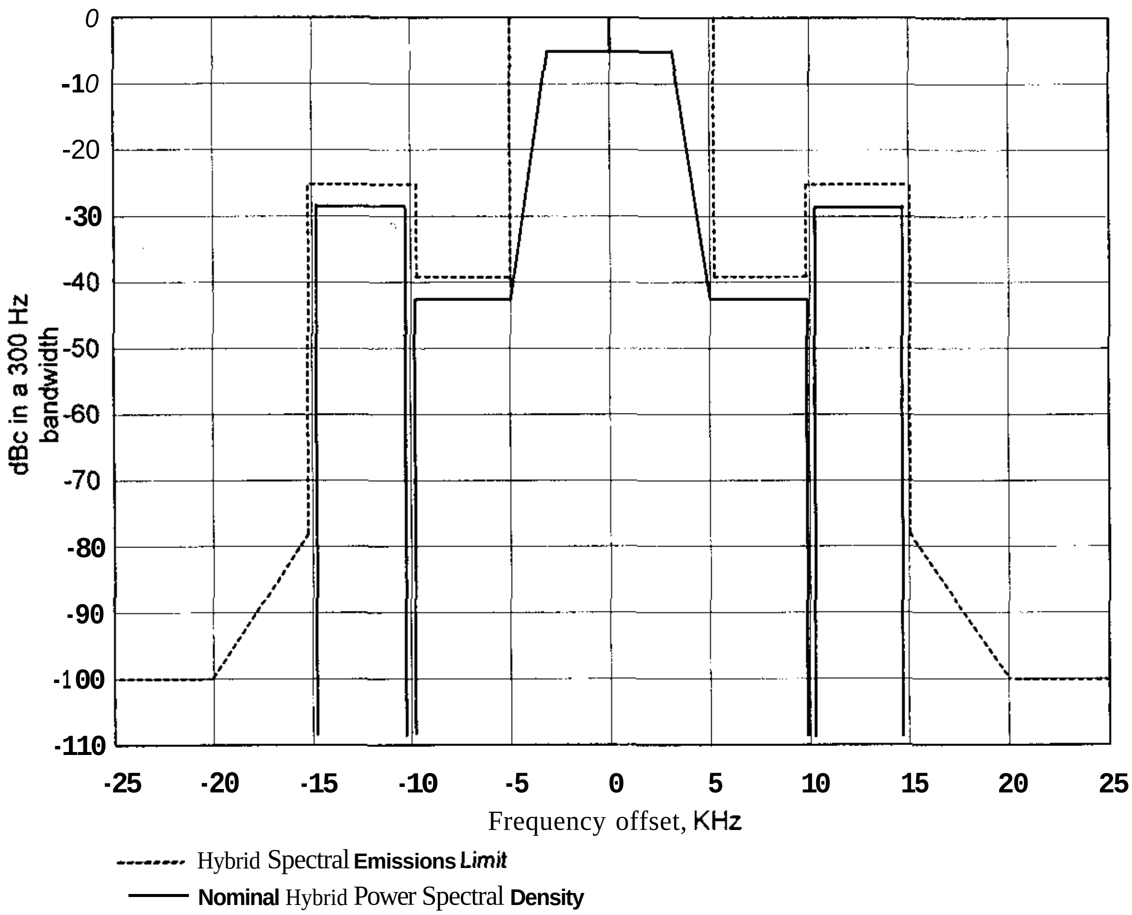

Figure 0-1 Recommended Spectral Emissions Limit for Hybrid Transmissions

Alternative Spectral Emissions Limit for All Digital Mode

The measured power spectral density of the all digital signal at frequencies removed from the carrier frequency by more than 300 Hz up to and including 5 kHz must not exceed -10 dBc/300 **Hz.**

The measured power spectral density of the all digital signal at frequencies removed from the carrier frequency by more than 5 kHz up to and including 10 kHz must not exceed -25 dBc/300 Hz.

The measured power spectral density of the all digital signal at frequencies removed from the carrier frequency by more than 10 **kHz,** up to and including 20.5 kHz must not exceed

-58 - (offset frequency in kHz - 10) * **4.0** dBc/ 300 Hz

The measured power spectral density of the all digital signal at frequencies removed from the carrier frequency by more than 20.5 **kHz,** must not exceed –100 dBc/300 **Hz.** Refer to Figure 6.2 for an illustration of the spectral emissions limit.

Measurements of the all digital signal will be made by averaging the power spectral density in a 300 **Hz** bandwidth over a 30-second segment of time. 0 dBc is defined as the allocated power of the uomodulated AM carrier and is equal to the reference level used in subsection 0. Refer to Figure 6.2 for an illustration of the spectral emissions limit.

The digital waveform will be measured to determine compliance with this section for transmitter type. Acceptance is to be made using signals sampled at the output terminals of the transmitter when operating into an artificial antenna of substantially zero reactance.

Measurements of operating station emissions are to be made at the transmitter's output sampling loop for non-directional stations or at the common point of a directional station.

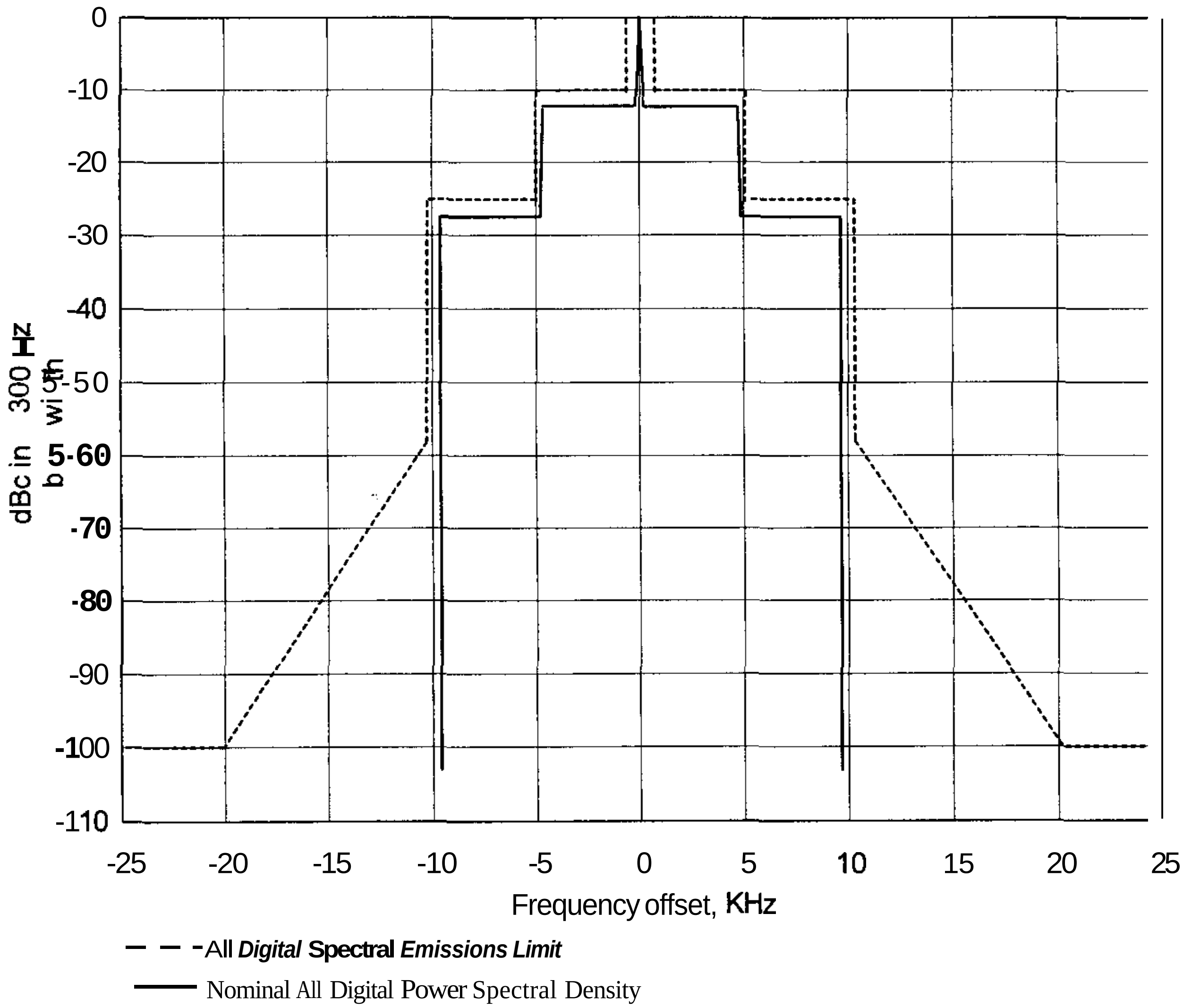

Figure 0-2 Recommended Spectral Emissions Limit for **All** Digital Transmissions

Additional Bandwidth Requirements

The system shall provide a means of-broadcasting only Class **3** digital audio and disabling Class **4** audio in order to reduce transmission bandwidth.

Digital Sideband Levels

The amplitude scaling of each OFDM subcarrier within each digital sideband is given in Table **6.3** for the Hybrid and **All** Digital waveforms. The amplitude scale factors are such that the average power in the constellation **for** that subcarrier meets the subcarrier levels shown in dB. For the Hybrid waveform, the subcarrier levels are specified relative to the total power of the unmodulated analog **AM** carrier (assumed equal to 1). For the **All** Digital waveform, the subcarriers levels are specified relative to the level of subcarrier **zero** (set to 1). The scale factors include **the** normalization factors shown in Table **6-2** for each modulation type.

The selection of CH_{S1}, CH_{T1}[ ], CH_{I1} versus CH_{S2}, CH_{T2}[ ], CH_{I2} is determined by the Power Level Control (PL) received from L2.

The amplitude scaling of each OFDM subcarrier within each digital sideband is given in Table *6-3* for the Hybrid

Modulation Type	Normalization Factor
BPSK	0.500
QPSK	0.707
16-QAM	1.581
64-QAM	3.240

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Table 0-3)FDM Su

Naveform	Sideband	Amplitude Scale Factor Notation	Modulation Type	Amplitude Scale Factor per subcarrier	Power Spectral Density, dB/Subcarrier
Hybrid	Primary	CH_P	64-QAM	9.76×10^{-3}	-30
	secondary	CH_{S1}	16-QAM	4.48×10^{-3}	-43
		CH_{S2}			
	Reference	CH_B	BPSK	1.00×10^{-1}	-26
	Tertiary	CH_{T1} [0]	QPSK	8.92×10^{-3}	{TBA}
		CH_{T1} [1]	QPSK	8.42×10^{-3}	{TBA}
		CH_{T1} [2]	QPSK	7.95×10^{-3}	{TBA}
		CH_{T1} [3]	QPSK	7.51×10^{-3}	{TBA}
		CH_{T1} [4]	QPSK	7.09×10^{-3}	{TBA}
		CH_{T1} [5]	QPSK	6.69×10^{-3}	{TBA}
		CH_{T1} [6]	QPSK	6.32×10^{-3}	{TBA}
		CH_{T1} [7]	QPSK	5.96×10^{-3}	{TBA}
		CH_{T1} [8]	QPSK	5.63×10^{-3}	{TBA}
		CH_{T1} [9]	QPSK	5.32×10^{-3}	{TBA}
		CH_{T1} [10]	QPSK	5.02×10^{-3}	{TBA}
		CH_{T1} [11]	QPSK	4.74×10^{-3}	{TBA}
		CH_{T1} [12:24]	QPSK	4.47×10^{-3}	{TBA}
		CH_{T2} [0:24]	QPSK	8.92×10^{-3}	{TBA}
Hybrid	IDS	CH_{I1}	16-QAM	4.48×10^{-3}	-43
		CH_{I2}	16-QAM	8.93×10^{-3}	-37
All Digital	Primary	CD_P	64-QAM	5.49×10^{-2}	-15
	Secondary	CD_E	64-QAM	9.76×10^{-3}	-30
	Tertiary	CD_E	64-QAM	9.76×10^{-3}	-30
	Reference	CD_B	BPSK	3.56×10^{-1}	-15
	IDS	CH_D	16-QAM	2.00×10^{-2}	-30

Analog Audio Source

The requirements in this subsection must be met to ensure that the existing analog signal does not significantly impact the performance of the digital subcarriers.

For hybrid mode operation, the power spectral density of the modulated **AM** carrier measured with the IBOC digital component disabled, at frequencies removed from the carrier frequency by more than **5** kHz (AAB=0) or 8 kHz (AAB=1) and up to **20 kHz** must not exceed **-75** dBc/300 Hz. 0 dBc is defined as the total power of the modulated **AM** carrier.

The analog signal may not exceed the modulation levels specified in Title **47** CFR **$73.1570:** "In no case shall the amplitude modulation of the carrier wave exceed 100% on negative peaks of frequent recurrence, or **125%** on positive peaks at any time".

IBOC is not compatible with existing analog **AM** stereophonic broadcasts. The input analog signal must be a monophonic signal.

JOINT STATEMENT OF COMMISSIONERS KATHLEEN Q. ABERNATHY AND KEVIN J. MARTIN

Re: ***Digital Audio Broadcasting Systems and Their Impact on Terrestrial Radio Broadcast Service, MM Docket No. 99-325***

We support today's decision selecting in-band, on-channel (IBOC) as the technology to be used by AM and FM broadcasters for the introduction of digital broadcasting. We commend the work of the industry for developing a model that will not require allocation of additional spectrum and will allow for an efficient transition to digital radio, during which time consumers will be able to receive their current services without disruption. Today's order allows broadcasters to initiate IBOC transmission on an interim basis, thus ensuring that the radio industry can begin to take advantage of the advancements that digital broadcasting has to offer.

As broadcasters face technological limitations and competitive challenges, the ability to move quickly toward digital audio broadcasting has become increasingly important. Digital radio will allow the industry to respond in a timely manner to the competition that they face from satellite radio services and holds great promise for the revitalization of AM service. In addition, the iBiquity system gives broadcasters the flexibility of providing auxiliary services. Thus, consumers will be able to receive a better quality audio signal now and may ultimately benefit from the development of innovative offerings, such as multiple audio streams and data and interactive services.

We do recognize that there may be some interference with existing services, but we believe that the impact will be minimal and is outweighed by the benefits of digital audio broadcasting. We are, however, particularly concerned about the potential for interference to some receivers used for radio reading services for the blind or visually impaired. We are pleased that the Commission will seek comment on measures to protect these established subcarrier services in its FNPRM. In the interim, we expect that broadcasters will work closely with the affected parties to resolve these issues without intervention from the Commission. We are optimistic that, in the short-term, interference issues can be resolved and, in the long-term, the quality and availability of radio reading services will benefit from the technological advancements of digital audio radio service.

SEPARATE STATEMENT OF COMMISSIONER MICHAEL J. COPPS

Re: ***In the Matter of Digital Audio Broadcasting Systems and Their Impact on the Terrestrial Radio Broadcast Service, MM Docket No. 99-325***

I am very pleased to support this item, which selects in-band, on-channel ("IBOC") as the technology to advance audio broadcasting into the digital future. Digital radio presents a tremendous opportunity for terrestrial radio broadcasters to compete with new technologies. It holds forth the promise of better quality sound – CD quality for FM, and FM quality for AM – which will enhance audio service generally and may well reanimate AM radio. But that's just for starters. Going beyond sound quality there will be multiple broadcaster opportunities in the provision of new auxiliary services, such as multiple audio programming channels, audio-on-demand services, and interactive features, too. All these, and perhaps more, will, I believe, enhance audio broadcasting measurably and in the process advance the public interest.

I want to congratulate industry for putting aside traditional competitive rivalries and working together toward the common goal of bringing the benefits of digital audio technology to the American people. It's a splendid example of private sector partnering, but it went even beyond that to include close cooperation and partnering with the public sector, too. The FCC also played a role here, and my hat is off to our Commission team members who put their shoulders to this task. To my mind, that's what makes this system of ours work best, with everyone working toward a common goal and the common good. It's a great model, and I would recommend it heartily for full application in other challenging areas, such as, for one example, the transition to digital television. I hope all the parties involved there will take note and follow suit. As I've said before, I am a believer, a true believer, in this kind of cooperative endeavor. In the competitive global economy we all inhabit, we work far more effectively when we work together.

A few questions remain to be settled, including how the IBOC system will function in the real world; what is the potential for and extent of interference that IBOC could cause to existing services; and the technical feasibility of nighttime AM IBOC transmissions. I believe the procedures put in place through this ***Order*** for resolving any interference issues that arise once interim transmissions begin are reasonable and effective and will enable the industry to address adequately and efficiently any and all such problems.

I look forward to the commencement of interim IBOC operations and to continuing to work with the industry to develop and finalize digital audio broadcasting standards. In Seattle, at the recent Radio Show, I saw first-hand some of the technology and equipment that will soon be available to bring digital radio to all of us. It's truly exciting.

Finally, my thanks to the Bureau for the hard work and dedication that went into making this happen.